First Movers Coalition

In collaboration with
Boston Consulting Group

SAF85 Technical Brief
Aviation Sector

WHITE PAPER

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Contents

1 Introduction

This document provides guidance on what constitutes 'SAF85' to FMC members looking to fulfil their aviation commitment.

1.1 Purpose

Launched in 2021 by US Special Presidential Envoy for Climate John Kerry and the World Economic Forum, the First Movers Coalition (FMC) is the leading global public-private partnership to scale emerging climate technologies to decarbonize heavy-emitting industrial sectors, including aviation.

FMC aviation sector members have made the ambitious commitment to procure sustainable aviation fuel that has at least 85% lower greenhouse gas emissions than conventional jet fuel – SAF85 – by 2030.

While many FMC aviation members have already managed to secure SAF85, the number and complexity of SAF production pathways and feedstocks on the horizon, as well as significant project-level nuances, make it difficult to identify products that meet FMC's high threshold. Each project, pathway, or feedstock can result in significant variations in carbon intensity, which can create confusion and deter action. FMC members have expressed the need for "rules of thumb" and key questions to ask suppliers to identify SAF that meets the FMC threshold.

Building on the 2023 FMC Sustainable Aviation Fuels Offtake Manual, this document aims to empower FMC members and companies along the fuel value chain and beyond as they look to purchase SAF85 by helping:

- **SAF buyers** understand the typical carbon intensity of different pathways, criteria to assess a project's potential to meet the FMC threshold and key questions to ask suppliers.
- **SAF producers** understand the requirements of FMC members, who represent one of the largest demand signals for sustainable aviation fuel in the world.
- **The broader SAF ecosystem** (e.g. airports, regulators, enabling technology developers) assess where the market is moving and which SAF pathways will be of high interest to ambitious movers over the next 5-10 years.

The document provides guidance on SAF pathways likely to meet the FMC commitment threshold, including rules-of-thumb for assessing SAF projects, based on the latest literature and input from FMC member organizations. However, it does not override the current FMC aviation commitment or serve as a peer-reviewed document.

Such guidance is intended to accelerate the procurement of SAF85 by FMC members and other ambitious corporates.

2 SAF85 overview

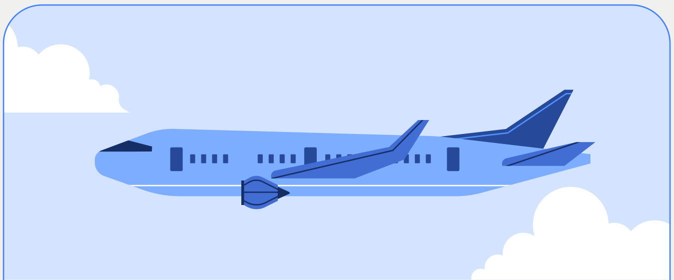
Several 'rules-of-thumb' can help members navigate the variety of SAF production pathways and feedstocks to identify supply that meets FMC commitments.

2.1 Understanding the First Movers Coalition aviation sector commitment

In the FMC aviation sector, members are classified as either airlines/airfreights (i.e. fuel purchasers) or airfare/airfreight purchasers and have made commitments as follows in Figure 1.

The commitment specifies that the carbon emissions calculation methodology underpinned by CORSIA, the Carbon Offsetting and Reduction Scheme for International Aviation, is the default system through which members should measure carbon emissions. This is because CORSIA has been fully adopted by the International Civil Aviation Organization (ICAO) as the scheme for reducing GHG emissions in international aviation.[1] Furthermore, the EU ETS,[2] US 40B SAF tax credit[3] and Civil Aviation Authority of Singapore (CAAS)[4] have adopted CORSIA as a key GHG emissions measurement scheme. However, the commitment language specifies that "similar frameworks" can also be used. For example, in addition to CORSIA, the US 40B SAF tax credit also accepts a new version of the GHGs, Regulation Emissions and Energy Use in Transportation (GREET) model,[5] which was released in April 2024; however, it only applies to a select few SAF pathways (*a comparison of similar frameworks is discussed in detail in section 5.3*).

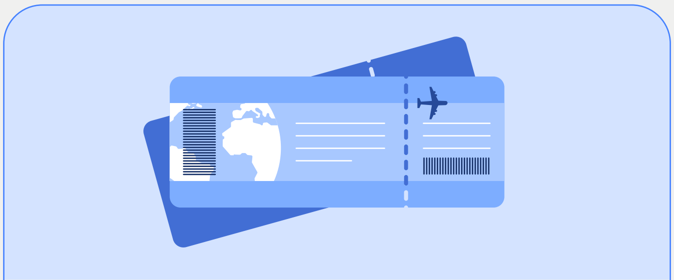
FIGURE 1 **First Movers Coalition aviation sector commitment language**



Airline / air freight

"

By 2030, we will replace at least 5% of conventional jet fuel demand with sustainable aviation fuels (SAFs) that reduce life-cycle GHG emissions by 85% or more when compared with conventional jet fuel,[1, 2] and/or zero–carbon emitting propulsion technologies.



Airfare / air freight purchaser

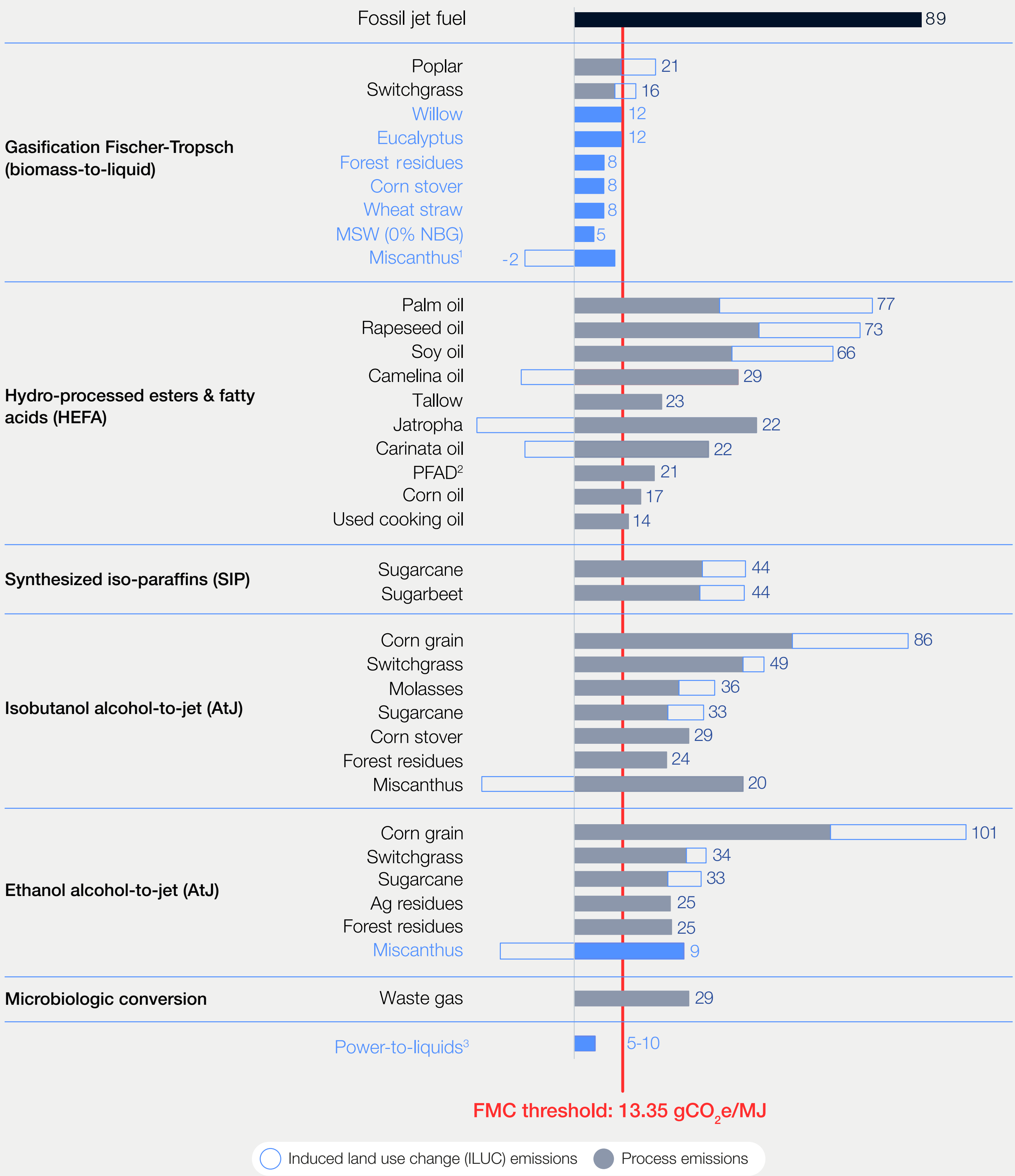
"

By 2030, we will partner with air transport operators to replace at least 5% of conventional jet fuel used for our air travel/freight with sustainable aviation fuels (SAFs) that reduce life-cycle GHG emissions by 85% or more when compared with conventional jet fuel,[1, 2] and/or zero-carbon emitting propulsion technologies.

1. FMC will use default values OR actual lifecycle analysis (LCA) using an eligible Sustainability Certification Scheme from CORSIA (or similar frameworks).
2. FMC intends to evaluate and potentially adopt PtL guidance for CO_2 and H_2 sources from CORSIA (or similar frameworks) once they are released.

According to the 2024 CORSIA Handbook,[6] the default baseline for fossil jet fuel is 89 grams of CO_2 equivalent per megajoule (gCO_2e/MJ), which means that **for SAF to meet the FMC ≥85% life-cycle emissions reduction commitment threshold, it must have a life-cycle carbon intensity at or lower than 13.35 gCO_2e/MJ, following CORSIA**.

FIGURE 2 **CORSIA default lifecycle carbon intensity of sustainable aviation fuels (gCO_2e/MJ)**



1. Negative ILUC values due to the high soil carbon sequestration and biomass carbon from producing cellulosic crops.
2. CORSIA also includes default values for HEFA co-processed at petroleum refineries, which is not included here because values are comparable or higher than their HEFA counterparts listed.
3. German Environment Agency (Umwelt Bundesamt).

2.2 Review of SAF pathways' potential to meet FMC threshold

Figure 2 compares the 30+ SAF pathways that CORSIA has published default carbon intensity values for.[7] Default values are a set of reference values that can be used by airlines for calculating the emissions of SAF in lieu of available project-specific values. It should be noted very clearly that a valid project-level life-cycle analysis using CORSIA or a similar framework always takes precedence over these default values.

For power-to-liquids (PtL), where CORSIA has not published a specific default carbon intensity value, the value is sourced from the German Environment Agency (Umwelt Bundesamt), which has published one of the most comprehensive power-to-liquids studies to date.[8]

There are few pathways where the default CORSIA value meets the threshold for SAF85, primarily concentrated in the Gasification Fischer-Tropsch (GFT, also called biomass-to-liquids or BtL). The German Environment Agency emissions intensity figure for power-to-liquids (PtL) technologies also meets the threshold for SAF85.

The default values for the four other specified pathways – hydroprocessed esters and fatty acids (HEFA), ethanol and isobutanol alcohol-to-jet (AtJ), synthesized isoparaffins (SIP) and microbiologic conversion – do not meet the FMC SAF85 threshold, with the exception of ethanol AtJ using miscanthus as feedstock (*miscanthus is discussed in detail in Section 5.4*).

However, SAF emissions vary widely from project to project, and due to variations in feedstock cultivation, transport and logistics, land-use change and the addition of technologies like carbon capture, other pathways could still meet the SAF85 threshold (*these sensitivities are discussed in detail in section 5.1 and 5.2*). For example, while used cooking oil (UCO) HEFA has a CORSIA default life-cycle value of ~14 gCO_2e/MJ, which is just outside of the FMC threshold, in practice, certain UCO HEFA projects may reduce emissions by greater than 85%. The IEA Bioenergy report "Comparison of Biofuel Life Cycle Analysis Tools: FAME and HVO/HEFA" cites four different models of cradle-to-pump emissions from UCO HEFA reaching the FMC threshold.[9] Despite the CORSIA default value for UCO HEFA suggesting an 85% life-cycle emissions reduction may not be possible, the pathway still has some potential to meet the FMC threshold and thus a project-level LCA should be conducted to determine if it meets the threshold.

Therefore, CORSIA default values should be considered a helpful reference point and only be used in the absence of a project-specific life-cycle analysis (LCA) that is conducted using the CORSIA methodology or similar frameworks. This document also presents a snapshot in time. As technology improves and evolves, the potential for feedstocks or pathways to meet the FMC threshold may change and expand.

The rest of this document will explore in more depth how members can think about the potential of each pathway to meet the FMC threshold, including a dedicated section on GFT and PtL, as well as a sensitivities analysis on the potential for additional low-carbon strategies to get the remaining pathways within the commitment threshold. **It is important to note that FMC is explicitly technology-agnostic in its aviation commitment as long as the fuel in question meets the emissions reduction criteria of the commitment.** With this in mind, Figure 3 summarizes the "rule of thumb" conclusions members can reference when assessing offtake for an SAF project.

While the following sections provide guidance on which SAF production pathway is likely to meet the 85% carbon emissions reduction threshold set by FMC, when exploring offtakes, FMC Aviation members should keep in mind other non-carbon criteria that could still impact the overall sustainability of the fuel, for example, competition with food (beyond the impact this will have on carbon stock, captured by land use change figures), water resources, soil and social development. CORSIA and equivalent methodologies underpin a list of criteria that fuels will need to meet to be considered sustainable.[10]

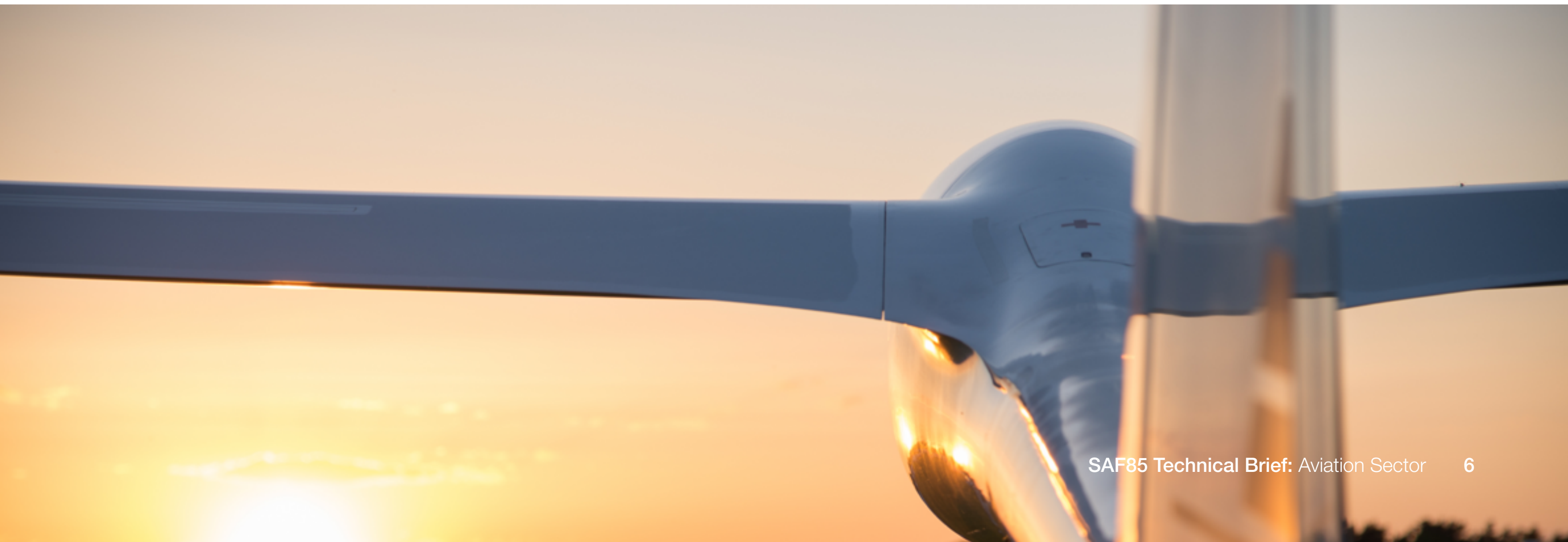
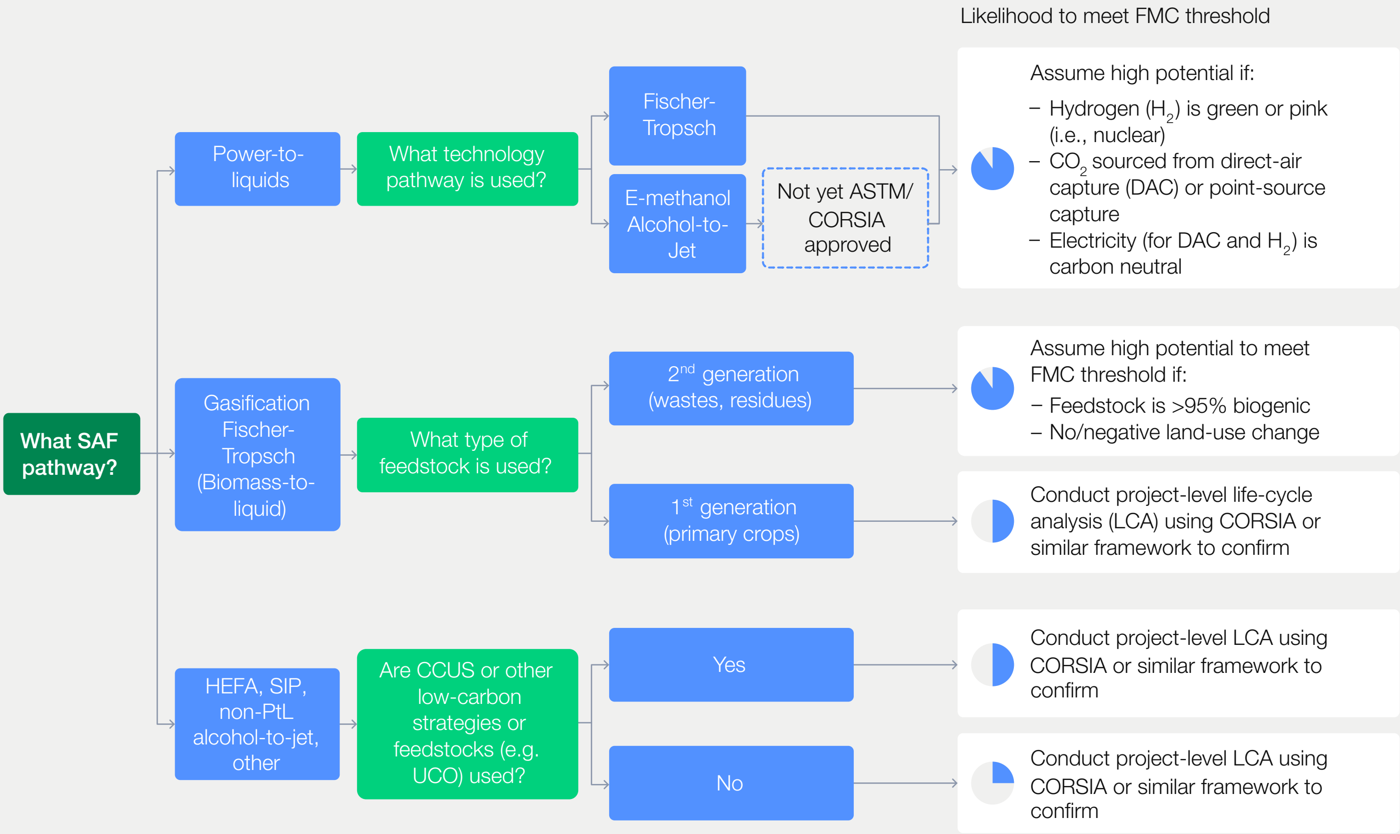


FIGURE 3 **Summary of project-level guidance on the potential of SAF pathways to meet the FMC commitment threshold**



3 Deep dive: Power-to-liquids

There is high interest in PtL because of its high carbon abatement potential, and thus likelihood to meet the FMC commitment.

EXECUTIVE SUMMARY

- Power-to-liquids (PtL) pathways, both Fischer-Tropsch PtL and e-methanol alcohol-to-jet (AtJ) PtL have a very high potential to meet the FMC threshold as long as they use green H_2, clean CO_2, and renewable electricity.
- While the e-methanol AtJ pathway is currently not an ASTM-approved conversion process, it is expected to be approved by 2030.
- Key questions to ask PtL SAF suppliers:
  - How is hydrogen being produced (e.g. gray, blue, green, pink) and from where is it being sourced (e.g. co-located facility, within same region/country, imported)?
  - Where is the CO_2 being sourced from (technology and geography)?
  - Where is the electricity being sourced for DAC and fuel conversion (geography and power generation technology)?
  - Following CORSIA or a similar methodology, is the final life-cycle carbon intensity at or below 13.35 gCO_2e/MJ?
  - For Fischer Tropsch, does the final product comply with ASTM D7566?

3.1 Technology overview

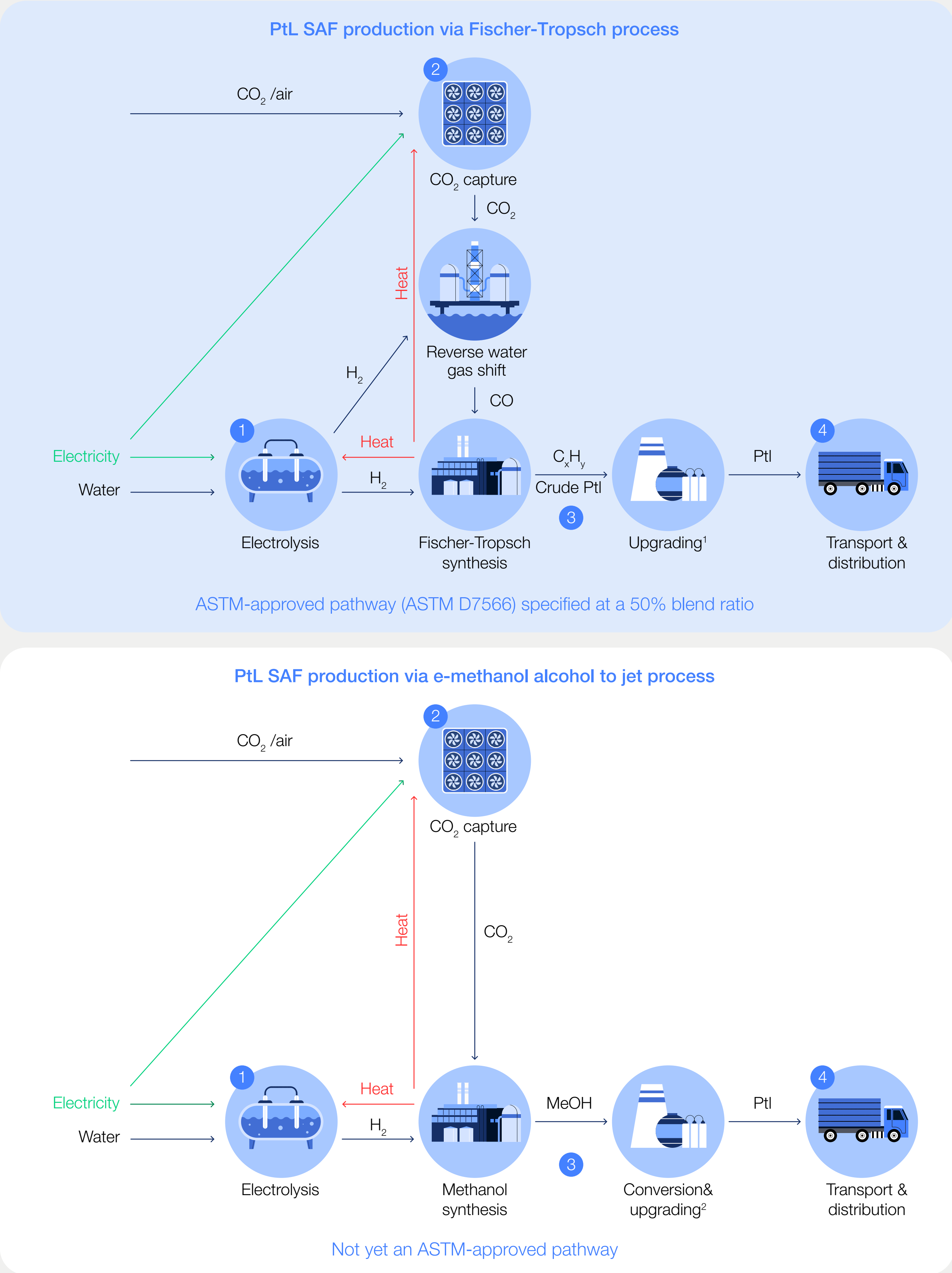
Power-to-liquids (PtL) fuels, also known as synthetic fuels, e-fuels, or renewable fuels of non-biological origin (RFNBOs), are produced with electricity as the primary energy source. As feedstock, they take hydrogen (H_2) from water and carbon dioxide (CO_2) from either the air (via direct air capture) or an industrial waste gas stream (via point-source carbon capture).[11] H_2 and CO_2 are combined to create a sustainable aviation fuel via two potential PtL pathways:

Fischer-Tropsch PtL: The Fischer-Tropsch pathway is the same as the second stage of the biomass-to-liquids conversion process, but uses a different feedstock. Rather than gasifying biomass feedstock, PtL Fischer-Tropsch takes a synthesis gas formed from a combined H_2 and CO_2 stream and forms it into a crude renewable hydrocarbon chain, which can then be upgraded to e-kerosene via hydrocracking, isomerization and distillation.

AtJ PtL: Alternatively, e-methanol (methanol formed synthetically through the combination of H_2 and CO_2) can be upgraded to e-kerosene via the alcohol-to-jet process (olefin synthesis, oligomerization and hydrotreatment). This process is similar to ethanol and isobutanol alcohol to-jet technologies, but uses e-methanol as a feedstock rather than biomass.

ASTM approval. For a SAF to be legal and safe to blend into jet fuel at airports, its thermo-chemical properties must comply with fuel specifications issued by ASTM International in the US – an internationally adopted standards organization for many materials – or by equivalent country-specific standards (e.g. Def-Stan 91-091 in the United Kingdom). These properties are specified in ASTM D7566,[12] which includes the technology used to produce the SAF and the maximum volumes it can be blended into jet fuel mix to produce safe drop-in jet fuel. Fischer-Tropsch PtL is approved via the FT-SPK pathway, currently approved for up to 50% blends with conventional jet fuel. However, while AtJ via ethanol and isobutanol are approved, AtJ via e-methanol has yet to be approved and given a blend ratio from ASTM. However, ICAO has indicated that this pathway is under evaluation by ASTM[13] and there are multiple e-methanol PtL plants planned to be operational before 2030,[14] indicating some confidence that this may change in the coming years.

FIGURE 4 | **Diagram of power-to-liquids technical production pathways**



1. Hydrocracking, isomerization and distillation.
2. Alcohol-to-jet process: Olefin synthesis, oligomerization and hydrotreatment.

Source: Adapted from Umwelt Bundesamt (German Environment Agency), Power-to-Liquids Report, Jan 2022.

3.2 GHG emissions from PtL

CORSIA has not released default life-cycle carbon intensity values for either PtL pathway. However, in part 1 of their report "CORSIA Eligible Fuels: Life Cycle Assessment Methodology" released in June 2022, ICAO lays out the process for adding default values, which requires sufficient scale and data to conduct a reliable LCA.[15]

In lieu of this, we reference a comprehensive report on PtL, which was published in January 2022 by Umwelt Bundesamt (the German Environment Agency).[16] The report estimates the life-cycle carbon intensity of PtL SAF to be between 5-10 gCO_2e/MJ, falling well within the FMC commitment threshold. While the majority of emissions are coming from the heat and electricity required for these processes, emissions in PtL pathways come from four stages throughout the fuel production process (see Figure 4):

1. **Hydrogen production (electrolysis)**. When the H_2 produced is green, this stage accounts for ~50-55% of total emissions, which primarily depends on the carbon footprint of the electricity used.

– *Note:* If the project in question is using H_2 that is not green, this will definitely increase the life-cycle emissions. If the project uses gray H_2 (hydrogen produced from steam-reforming natural gas), it is unlikely to meet the FMC emissions threshold, and if it uses blue H_2 (gray H_2 with carbon capture) its carbon intensity likely depends on the capture rate of blue H_2 and a project-specific LCA should be conducted to determine the carbon intensity of the SAF. Pink H_2 (i.e. H_2 produced using nuclear power) should be treated similarly to green H_2 because it still uses the water electrolysis process and the energy source has a low carbon footprint.[17] While no SAF PtL projects announced to date have specified plans to use non-green H_2 as a feedstock,[18] attractiveness of blue H_2 due to economics and policy incentives (e.g. potentially restrictive standards on green H_2 for the United States 45V tax credit[19]) may increase the likelihood of this in the future.

2. **CO_2 supply (capture).** This accounts for 30-35% of total emissions, primarily from electricity.

– *Note:* CO_2 can be sourced from either direct air capture (DAC) or from point-source carbon capture (i.e. from industrial waste gases) to fulfill FMC commitments. This is in line with the European Union's Renewable Energy Directive (RED II)[20] as well as the UK SAF Mandate.[21] Point-source capture includes the capture of biogenic CO_2 (e.g. carbon captured from a biomass power plant, or BECCS) or fossil CO_2 (e.g. carbon captured from a refinery). Fossil CO_2 as a feedstock is inherently less sustainable than DAC or biogenic CO_2 because the carbon that will eventually be burned as jet fuel is still coming from a fossil source, while the carbon from DAC or biogenic CO_2 was originally removed from the air. Therefore, beyond 2030 and the scope of the current FMC commitment, perspectives on this point are likely to change.* However, in the short term, one tonne of PtL jet fuel produced with point-source capture as a feedstock is still displacing one tonne of fossil jet fuel. Because DAC is more expensive and less available today, and in the long term, it is relatively easy to switch CO_2 feedstocks, point-source capture should be considered a viable feedstock for PtL, though non-biogenic point source CO_2 must still be accounted for (i.e. by the point-source emitter, PtL fuel producer, aircraft owner, etc). If the project does source CO_2 from DAC, it should ensure the electricity source is low-carbon (e.g. renewable, nuclear).

3. **Synthesis and conversion.** This accounts for 5-15% of total emissions, primarily from heat and electricity

– *Note:* The carbon intensity of PtL fuel does not assume any process synergies that could be realized from co-locating steps in the process (e.g. reuse of waste heat), which have additional potential to reduce carbon intensity.

4. **Distribution.** This accounts for <5% of total emissions.

*As guidance on carbon capture is currently provided until 2030 only, in line with feedback gathered from the FMC community, should FMC criteria for CO_2 capture be tightened in the future (e.g. potential exclusion of point-source carbon capture), any existing SAF offtake agreement relying on point-sources signed before any potential guidance changes are announced would still be considered as meeting the FMC commitment.

3.3 Additionality of renewable electricity for power-to-liquids fuels

Because PtL pathways utilize renewable electricity, this raises a key question on the additionality of the renewable electricity used. Additionality (also known as incrementality) means that the power used to produce the fuel is net new renewable power, rather than renewable power that was already in use. The purpose of this concept is to ensure that new e-fuel production does not divert or subtract renewable power from elsewhere, but rather directly adds renewable power to the global energy mix. While CORSIA does not have published guidance on additionality because it has yet to publish guidance broadly on e-fuels, GREET, the UK SAF mandate and the Renewable Energy Directive all take a position.

GREET uses guidance from the 45V hydrogen production tax credit for its incrementality requirement.[22] Specifically, it proposes that renewable power "meets the incrementality requirement if the electricity generating facility that produced the unit of electricity to which the energy attribute certificate (EAC) relates has a commercial operational date (COD) (as defined in proposed § 1.45V-4(d)(2)(i)) that is no more than 36 months before the hydrogen production facility for which the EAC is retired was placed in service."

The UK SAF mandate also provides guidance on additionality. It states that energy taken from the grid must be taken as a grid average for a national or regional grid,[23] which is likely not clean enough to meet today's GHG emission savings threshold (therefore also making it not clean enough to meet the FMC commitment threshold – see section 5.3 for more detail). The mandate asks PtL fuel producers to follow Renewable Transport Fuel Obligation (RTFO) guidance on additionality, that "the renewable electricity used in RFNBO production is considered to be 'additional renewable energy' if the electricity would not have been produced, or would have been wasted, if not consumed by the RFNBO production site."[24] It further specifies this can be achieved through new electricity with a direct line to a fuel production plant (with or without grid connection), with additional capacity via an electricity grid, or by using renewable electricity that would otherwise have been wasted.

Finally, the **Renewable Energy Directive** has an additionality requirement for hydrogen and other RFNBOs which states that "the rules require hydrogen producers to conclude power purchase agreements (PPAs) with new and unsupported renewable electricity generation capacity."[25]

FMC does not have a stance on additionality in this context, but FMC members should be aware of and consider the additionality requirements of the regulatory environment in which they are exploring offtake with a potential SAF project.

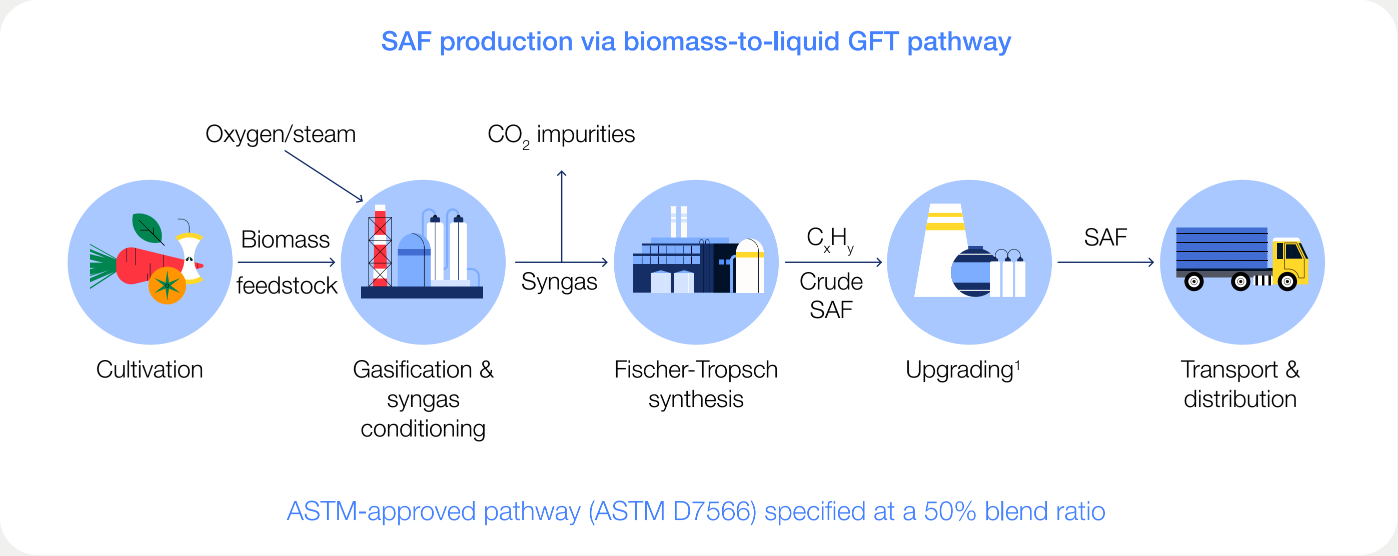
4 Deep dive: Gasification Fischer-Tropsch (biomass-to-liquids)

For GFT pathways, it is critical to consider feedstock and land use change implications.

EXECUTIVE SUMMARY

- Gasification Fischer-Tropsch (GFT) using second-generation (2G) biomass feedstocks (e.g. wastes, residues) has high potential to meet the FMC threshold as long as the feedstock is >95% biogenic and has no or negative attributed land-use change.
- GFT using first-generation (1G) biomass feedstocks (e.g. primary crops like poplar, switchgrass) has some potential to meet the FMC threshold; however, a project-level LCA should be conducted to determine carbon intensity.
- Key questions to ask GFT SAF suppliers:
  - What feedstock is being used to produce the SAF? Is it a primary crop (1G) or a waste, byproduct, residue (2G)?
  - If the feedstock is a mixed waste stream (e.g., municipal solid waste (MSW), wood/yard waste), what percentage biogenic content is it?
  - Following CORSIA or a similar methodology, are there land-use change emissions attributed to the SAF?
  - Following CORSIA or a similar methodology, is the final life-cycle carbon intensity at or below 13.35 gCO_2e/MJ?
  - Does the final product comply with ASTM D7566?

FIGURE 5 **Diagram of Gasification Fischer-Tropsch technical production pathways**[26]



1. Hydrocracking, isomerization and distillation.

Source: Adapted from European Technology and Innovation Platform, Fischer-Tropsch Synthesis Bioenergy Fact Sheet, 2021.

Fischer-Tropsch is a process of converting (synthesis gas or syngas) composed of CO and H_2 into SAF. It was developed in the 1920s by Franz Fischer and Hans Tropsch and theoretically can take any feedstock that can supply CO and H_2 components (including fossil fuels, biomass, and synthetic H_2 and CO_2 which were discussed in the PtL deep dive).[26] This section is focused on converting biomass sources into SAF, also known as biomass-to-liquids. The technical process is laid out in Figure 5.

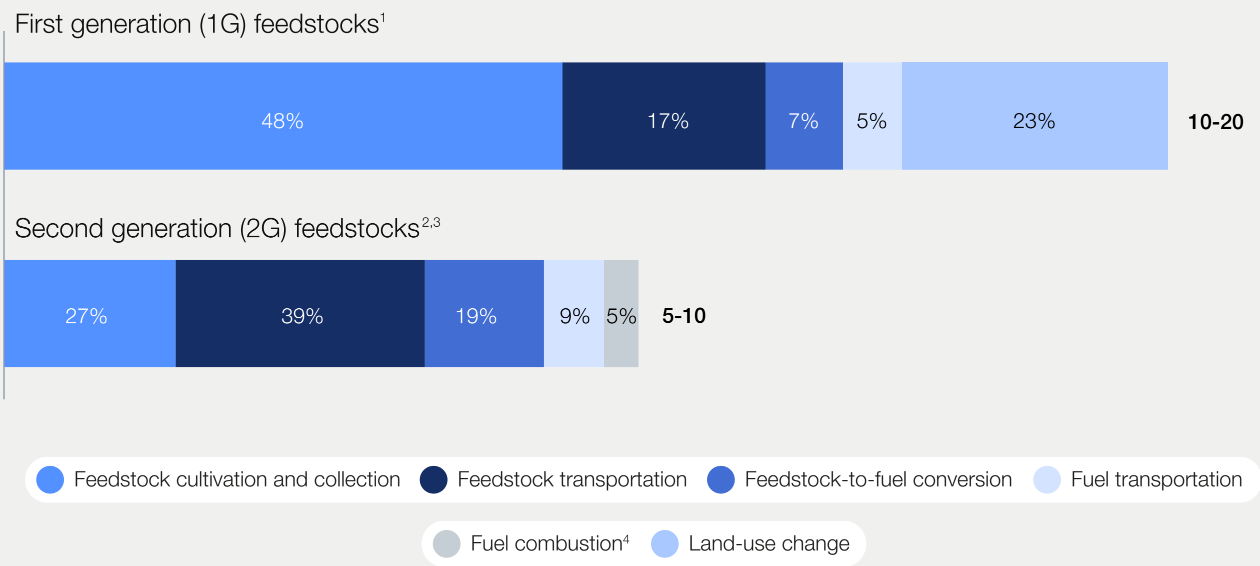
The most important factor determining whether a project will meet the FMC threshold is feedstock. Biomass feedstocks for GFT fall into two categories: first-generation (1G) and second-generation (2G).

"**First-generation** feedstocks" refer to primary crops grown for the purpose of using as feedstock for biofuel production. This includes poplar, switchgrass, willow, eucalyptus and miscanthus.

"**Second-generation** feedstocks", on the other hand, refer to waste products, byproducts and other residues, including >95% biogenic municipal solid waste (MSW), forest residues, corn stover and wheat grass. The main difference in emissions lies in feedstock cultivation, where 1G feedstocks tend to have 2-3x the emissions of 2G feedstocks, and in land-use change, where 2G feedstocks typically have no significant associated emissions.

For MSW, which typically has a wide range of biogenic content, CORSIA has published a formula for calculating the default value by percentage of non-biogenic content. The reason this formula exists is that fuel combustion emissions must be counted for SAF produced using non-biogenic content. As this content goes up, counted fuel combustion emissions rise proportionally. **However, while unlikely, if the MSW is >95% biogenic, its default value is within the FMC threshold**. While it is not included in the default value, CORSIA additionally allows credits for avoided emissions from landfills (LECs) and credits for additional material recovery (RECs), which can be understood in detail in the "CORSIA Methodology for Calculating Actual Life Cycle Emissions Values" document.[27]

FIGURE 6 **Emissions profile of first-generation vs second-generation feedstocks (gCO_2e/MJ)**



1. Includes poplar, switchgrass, willow, eucalyptus; excludes miscanthus as an outlier, which is covered separately.
2. Includes MSW (>95% biogenic), forest residues, corn stover, and wheat straw.
3. Bar totals 99% due to rounding error.
4. Combustion emissions only counted from non-biogenic content, primarily from MSW.

5 Additional analyses

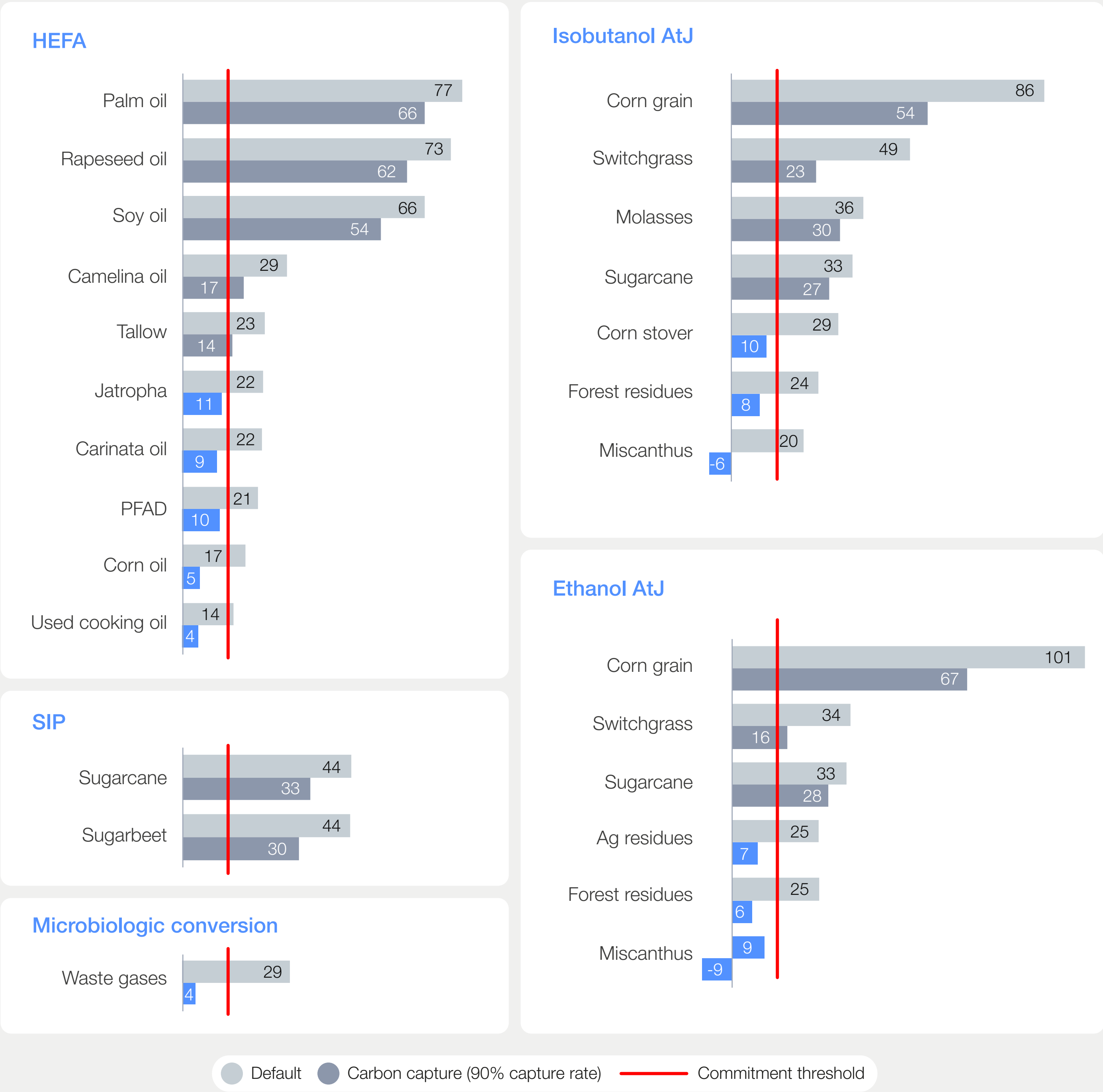
Other factors affect compliance with the FMC commitment, including carbon capture and carbon accounting methodologies.

5.1 Impact of carbon capture on SAF pathways

Figure 7 shows the potential of each pathway to meet the FMC commitment threshold if carbon capture is used throughout the fuel conversion process, assuming a 90% capture rate,[28] which the IEA describes as typical for industrial plants operating today.

In this analysis, carbon capture was only symbolically applied to the fuel conversion emissions (i.e. emissions from feedstock cultivation, transportation and land-use change would not be eligible for carbon capture). The results show that many HEFA and AtJ pathways have the potential to meet the FMC commitment threshold if carbon capture is used; however, SIP remains beyond the threshold. No analysis was conducted on the technical feasibility of carbon capture on these processes, and there are no SAF plants today using carbon capture. For a new SAF project claiming to use carbon capture, these values should not be taken as default and a project-level LCA should still be conducted by the supplier.

FIGURE 7 **Theoretical impact of carbon capture on SAF pathways potential to meet FMC commitment threshold (gCO_2e/MJ)**



Source: CORSIA, FMC analysis and IEA.

5.2 Impact of induced land-use change of SAF pathways

Another variable that is project-specific and makes up a large portion of emissions for certain pathways is induced land-use change (ILUC). CORSIA defines ILUC to include three major sources of emissions:[29]

1. Emissions due to changes in vegetative living biomass (natural vegetation and average agricultural landscape) carbon stock
2. Emissions due to changes in soil carbon stock
3. Emissions debt equivalent to forgone carbon sequestration

CORSIA has triangulated the results of two models that estimate ILUC at both global and regional levels for SAF pathways that have available data. CORSIA also labels some pathways as "low risk" for ILUC,[30] particularly:

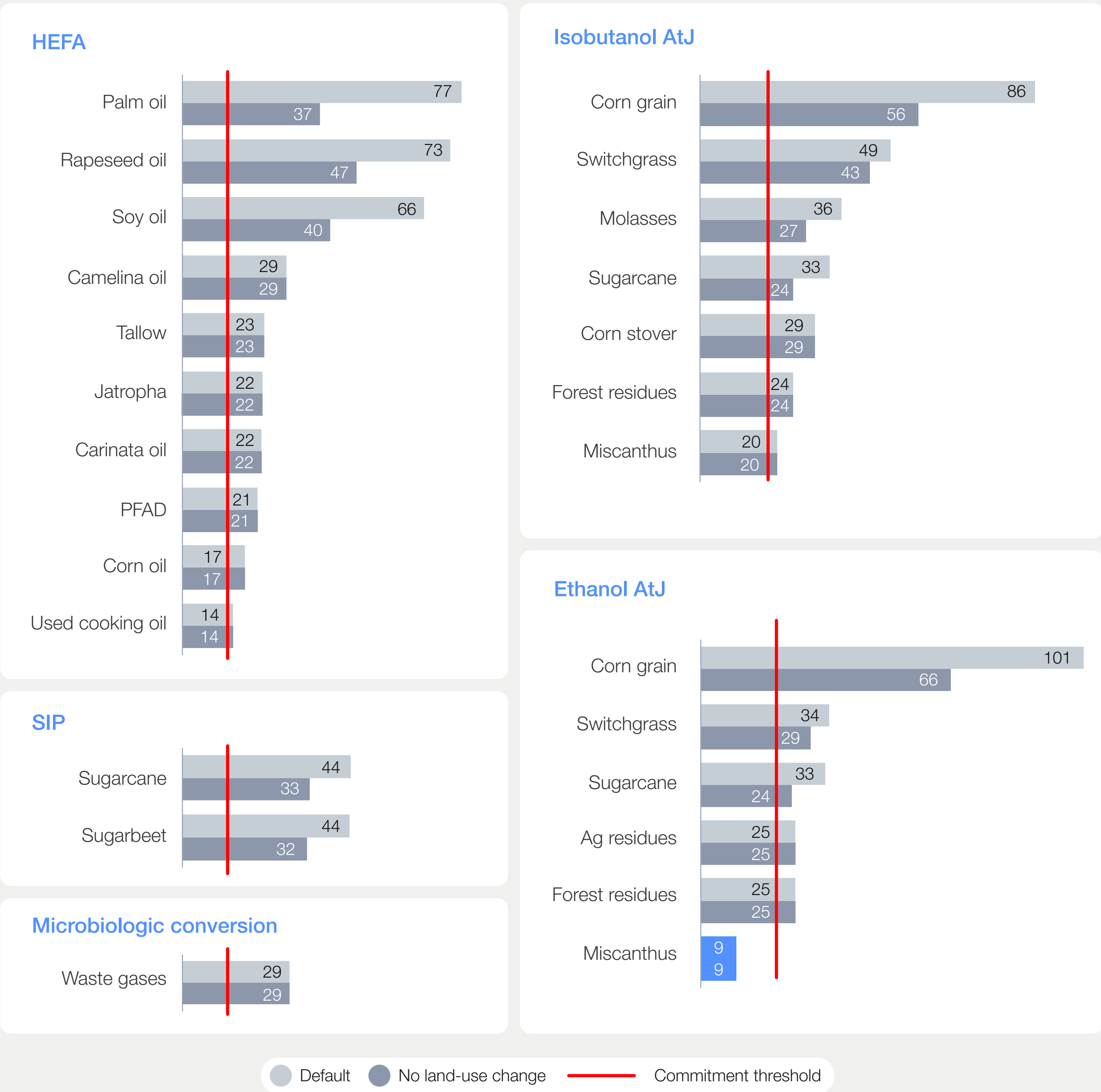
1. Feedstocks that do not result in expansion of global agricultural land use for their production

2. Wastes, residues and by-products

3. Feedstocks that have yields per surface unit significantly higher than terrestrial crops (e.g. some algal feedstocks)

Because the FMC commitment specifically includes ILUC in its calculation, it is necessary to calculate or estimate land-use change at the project level for any SAF pathway that has a non-zero ILUC default value.

FIGURE 8 **Impact of ILUC on SAF pathways potential to meet FMC commitment threshold (gCO_2e/MJ)**



Source: CORSIA, FMC analysis and IEA.

Figure 8 shows the impact of eliminating ILUC (i.e. if assumed ILUC was zero unless the default ILUC value is negative) for each SAF pathway.

As Figure 8 demonstrates **there are no SAF pathways that were previously low likelihood of meeting the FMC commitment threshold that, with the minimization of ILUC, are able to meet the FMC threshold**. Many values do not change because those pathways did not have attributed land-use change to begin with. This analysis does not consider a situation where a pathway has negative ILUC emissions (that was not already negative in the default value). If a project claims to have negative ILUC, a project-specific LCA is needed to assess the carbon intensity of the SAF. Please note that different carbon emissions methodologies may treat direct and indirect land-use change differently as well.

5.3 Comparison of CORSIA to other standards and emissions methodologies

CORSIA is not the only standard and emissions calculation methodology that exists today. Other similar frameworks include the European Union's recast Renewable Energy Directive (RED II), the UK Renewable Transport Fuel Obligation (RTFO) and the US Greenhouse Gases, Regulated Emissions & Energy Use in Transportation (GREET) models.

FIGURE 9 **Comparison of relevant standards and emissions methodologies**

	CORSIA Carbon Offsetting and Reduction Scheme for International Aviation	**RED II** Renewable Energy Directive	**UK SAF Mandate**	**GREET** GHGs, Regulated Emissions, & Energy Use in Transportation
Adopted by	ICAO, US 40B SAF credit, EU ETS, CAAS	RefuelEU Aviation	UK aviation industry (expected to begin 2025)	US 40B SAF credit
What qualifies as a SAF	Reduction of 10% or more from 89 gCO_2 e/MJ baseline	Reduction of 70% or more from 94 gCO_2 e/MJ baseline[1]	Reduction of 40% or more from 89 gCO_2 e/MJ baseline	Reduction of 50% or more from 89 gCO_2 e/MJ baseline

Methodology	Total emissions ⊜
	⊕ Emissions from feedstock cultivation
	⊕ Emissions from feedstock harvesting, collection and recovery
	⊕ Feedstock processing and extraction
	⊕ Feedstock transportation
	⊕ Feedstock-to-fuel conversion
	⊕ Fuel transportation & distribution
	⊕ Fuel combustion
	⊕ Land use change
		Total emissions ⊜
		⊕ Extraction or cultivation of raw materials
		⊕ Carbon stock changes caused by land-use change
		⊕ Processing
		⊕ Transport and distribution
		⊕ Fuel use
		⊖ Soil carbon accumulation via improved agricultural mgmt
		⊖ Carbon capture and geological storage
		⊖ Carbon capture and replacement
		⊖ Excess electricity from cogeneration
			Total emissions ⊜
			⊕ Extraction or cultivation of raw materials
			⊕ Carbon stock changes caused by land-use change
			⊕ Processing
			⊕ Transport and distribution
			⊕ Fuel use
			⊖ Soil carbon accumulation via improved agricultural mgmt
			⊖ Carbon capture and geological storage
			⊖ Carbon capture and replacement
				Total emissions ⊜
				⊕ Feedstock growing, harvesting, transporting and processing of primary feedstock material
				  ⊖ Carbon capture and sequestration (for ethanol only)
				⊕ Fuel production, transport between intermediate facilities, and transport to blending terminals and airports
				⊕ Combustion (i.e. non-CO_2 emissions from SAF combustion)
				⊕ Indirect effects
				  ⊕ Induced land use change
				  ⊕ Other crops
				  ⊕ Livestock
				  ⊕ Rice methane
				⊖ Valorized co-products

1. EU baseline is not for SAF specifically, but rather generally for advanced biofuels (e.g. biodiesel, ethanol).

The Renewable Energy Directive underpins a methodology for calculating emissions of biofuels that have been adopted by the ReFuelEU Aviation SAF mandate.[31] Whereas CORSIA only requires a GHG emissions reduction above 10% from fossil fuels, RED II requires a reduction above 70%. This has no implications for FMC specifically because the FMC commitment threshold is higher, at ≥85%.

RED II does publish default values. However, these do not include SAF specifically, but rather other biofuels including biodiesel, biogas and ethanol. Therefore, they cannot be directly compared to CORSIA. Finally, while the exact language of the calculation methodology differs from CORSIA, both largely include the same components. The main differences lie in RED II's subtraction of emissions from carbon capture, soil accumulation, and excess electricity from cogeneration, and the lack of a standalone entry for indirect land use changes.* CORSIA does not have specific guidance about the application of carbon capture or excess electricity and it includes soil accumulation emissions in its calculation of ILUC. Additionally, both methodologies specifically exclude emissions from equipment/machinery manufacturing.

The UK SAF mandate is a regulatory measure to deliver UK GHG emissions reductions from the aviation sector in line with the UK government's 2022 Jet Zero Strategy.[32] SAF certificates in the UK have been tradeable under the Renewable Transport Fuel Obligation (RTFO) since 2018, however, the UK SAF mandate, for which detailed guidance was released in April 2024, will replace this initiative. It is set to begin in 2025 and will keep the RTFO's emissions calculation methodology. This methodology follows very similarly to RED II.[33] The most important difference is that the UK SAF mandate's calculation methodology does not include a subtraction for emissions from excess electricity from cogeneration. The UK government has decided that while total default values will not be provided, disaggregated default values will be provided for downstream emissions, which will be published in upcoming mandate guidance.

GHGs, Regulated Emissions and Energy Use in Transportation (GREET) is a collection of life-cycle emissions calculation methodologies and models developed by the Argonne National Laboratory for companies to assess the emissions intensity of sustainable fuels.[34] In April 2024, the Argonne National Laboratory released a new GREET model for SAF, which has been approved for companies to use to capture the 40B SAF tax credit laid out in the Inflation Reduction Act (IRA).[35] There are also voluntary certifications from RSB and ISSC, such as the use of CORSIA or any similar methodology. The new GREET model has now been approved as a similar methodology.[36]

GREET does not supply or plan to supply default values for SAF pathways, but does provide an emissions calculator Excel file that can be used to estimate the LCA of a specific project. It also at this point only covers seven SAF pathways:

1. US soybean HEFA
2. US and Canadian canola/rapeseed HEFA
3. Tallow HEFA
4. Used cooking oil (UCO) HEFA
5. US distillers corn oil HEFA
6. US corn AtJ ethanol
7. Brazilian sugarcane AtJ ethanol

The implication of this is that for other SAF pathways (notably GFT and PtL which are of high interest for the FMC threshold), CORSIA remains the primary emissions calculation methodology to access the 40B SAF tax credit.

While the language of GREET is considerably different than CORSIA, RED II, or the UK SAF mandate, in practice, these methodologies remain very similar. The key difference is that GREET allows for the subtraction of emissions from valorized co-products. This means that if a co-product (e.g. distillers corn oil from ethanol AtJ) of SAF production is sold by the oil, ethanol, or SAF producer or otherwise productively used, it can qualify for a credit towards the SAF's total emissions. The implications are that, in the United States, a SAF plant that can produce approved co-products (*list available in the GREET user manual*)[37] may have a lower carbon intensity using the GREET methodology than using CORSIA.

Beyond government-driven methodologies like RED II, the UK SAF mandate and GREET, there are other GHG methodologies and certification frameworks developed by non-governmental organizations, including certifications developed by the **Roundtable on Sustainable Biomaterials (RSB)**[38] and the **International Sustainability and Carbon Certification (ISCC)**.[39] Both offer multiple certifications including RSB Global Fuels Certification and ISCC PLUS, that are based on sustainability principles developed by these organizations as well as certifications that specifically meet the underlying criteria for CORSIA (internationally) and RED II (in the EU).

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*RED II however sets limits on the use of biofuels that present high ILUC risks or a potentially significant expansion in land with high carbon stock.

RSB EU RED Fuel Certification and ISCC EU Certification ensure compliance with EU sustainability criteria and traceability requirements for biofuels and bioliquids. It is important to note that ISCC EU is already formally recognized by the EU while RSB EU RED Fuel Certification is currently in the process of being recognized. Additionally, RSB CORSIA Certification and ISCC CORSIA Certification ensure eligibility under CORSIA, and both are formally recognized by ICAO.

The FMC commitment language specifies that "CORSIA or similar frameworks" can be used. **GREET, RED II and the UK SAF Mandate and other methodologies that ensure compliance with either CORSIA or these frameworks should therefore be considered acceptable to calculate life cycle emissions for the geographies and pathways they include in scope.**

5.4 Novel SAF pathways not specified in this document

This document has focused on SAF pathways that are officially recognized by CORSIA or are otherwise of high interest to members based on future viability and/or potential to meet the ≥85% commitment threshold (e.g. PtL). However, it is likely that in the future other SAF pathways will continue to be developed. One example that is very nascent, but with high potential, is renewable natural gas (RNG) to SAF via Fischer Tropsch synthesis or Methanol-to-Jet conversion.[40] RNG, also known as biomethane, is a refined biogas, which can be produced through anaerobic digestion of biomass waste, and is an established, scalable technology today.[41] Due to its nature as a waste feedstock (i.e. minimal ILUC and feedstock cultivation emissions) and use of power-to-liquids conversion processes RNG to SAF could have the potential to meet the FMC threshold, but it has not been explored in depth given the nascency of the pathway.

As a general guideline, **a project-level LCA should be conducted using CORSIA or similar methodology on any novel SAF pathway that is not specified in this document to confirm that it meets the FMC threshold. Additionally, it should be confirmed that the novel SAF pathway in question is approved under ASTM 7566.**

5.5 Miscanthus and other feedstocks

CORSIA default values for miscanthus attribute to it the highest negative ILUC emissions of all other feedstocks. This suggests that miscanthus AtJ SAF would well be within the FMC commitment threshold, and miscanthus GFT SAF could even reach a negative emissions value, despite the rule of thumb framework provided (Figure 3).

Miscanthus could achieve negative ILUC emissions due to its unique ability to "store roughly half of the carbon it removes from the air below ground, building extensive root and microbial systems that enrich soil."[42] This means that for every tonne of CO_2 in harvested miscanthus biomass, another tonne of CO_2 could be stored underground. Other feedstocks like jathropa, carinata and brassica may also reach high negative ILUC emissions according to the CORSIA default values.

There are very few cases to date of such feedstocks being used for SAF, primarily in the United States, however, they do claim over 100% GHG emissions reduction compared to conventional jet fuel. While these early findings indicate there may be promising and unique feedstocks for multiple SAF technology pathways with a high potential to meet the FMC threshold, **FMC recommends that a more detailed assessment of the ILUC implications is conducted when fulfilling the SAF85 FMC commitment through fuels produced from such feedstocks.**

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